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RIVER SURVEYS IN UNMAPPED TERRITORY

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WATERWAYS DIVISION

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RIVER SURVEYS IN UNMAPPED TERRITORY

Gerard H. Matthes,[1] Hon. M. ASCE

SYNOPSIS

Methods are presented calculated to be of assistance to engineers detailed on foreign missions concerned with river utilization problems in unmapped areas, and where streamflow data generally are lacking. The subject is treated under two heads: (a) short-cut methods adapted to exploratory or reconnaissance surveys which limit engineers to the use of hand instruments, slide rule, and expedients for estimating river discharge and river gradients; (b) methods of providing reliable surveys of specific local areas, and also more extensive maps, which include the use of aerial photogrammetric methods. Convenient tables and diagrams are submitted. The hope is expressed that additional methods of this nature may be submitted by other engineers as the fruits of their experience.

The growing demand for expert advice in matters pertaining to water resources utilization in regions as yet unmapped, or only partly mapped, has prompted the outlining herein of field methods which experience has shown to be of considerable assistance whenever conditions require instrumental equipment and personnel to be reduced to a minimum. Besides surveying and mapping methods, some of which rate no better than expedients, short-cuts for estimating river gradients and discharge are presented.

Exploratory or Reconnaissance Surveys

Exploratory work, being as a rule of a tentative character, differs basically from the accurate final surveys that must follow once a river project has reached the status where its development becomes assured. The exploratory phase recalls the situation that confronted engineers some fifty-five years ago in the arid western section of the United States, then largely unsurveyed and devoid of streamflow records. Prospective irrigation development then was the keynote, and every ranchman, even the village grocer could direct one to what he considered to be a good dam site. Today, the limitations confronting the engineer called upon to report on foreign project possibilities are more severe owing to differences in languages, local customs and modes of travel. In exploratory work the mode of travel usually determines the type of instrumental equipment. In most cases this must be held down to articles that can be carried in coat pockets or traveling bag, such as compass, hand level or clinometer, aneroid, stopwatch, tape, slide rule and magnifying glass. For the purposes of this paper it is assumed that even a current meter must be ruled out. Certain items can be added, however, to the above list depending upon the facilities for travel that the country affords. Among them is the rolled graduated cloth strip that can be nailed to a pole to serve as leveling or stadia rod; a camera with tripod; and a barometer of the

1. Cons. Hydr. Engr., New York, N. Y.

Paulin type. This latter instrument, however, is too delicate for rough travel, as on horse or camel back. A first reconnaissance by airplane, or hydroplane is always helpful toward gaining a comprehensive view of the river, its valley and tributary characteristics, and the extent of settlements, roads or trails. When a river is at all navigable, it is better to travel by water in whatever type of craft is in local use, than on land, employing native boatmen thoroughly familiar with the river. The need for an interpreter in the party is essential. Traveling upstream has the advantage of giving ample time for detailed study of the river, its banks, bars, shoals, islands and split channels. Since no two rivers are alike nothing should be taken for granted, and frequent inquiries are necessary. Native boatmen have a fund of information relating to low-water depths on shoals, the kind of craft used for transporting freight, the height and frequency of floods, their seasonal occurrence, and the extent of flood-plain lands overflowed.

Alluvial river characteristics are not limited to the lower courses of rivers. Our 1800-mile long Rio Grande, for instance, traverses a succession of canyons alternating with alluvial plains. Our Colorado River meanders in an alluvial valley at an altitude of 7200 ft. Streams of this type are worthy of detailed study as they afford potential sites for high dams and large reservoirs. On the other hand, such streams pose difficult problems as regards reconnaissance procedure, since travel through mountain gorges and box canyons can be done, as a rule, only on foot, rarely by boat or on horseback. In open valleys horseback travel is to be recommended. In this connection, it has been the writer's experience that for determining distances by pacing, a horse does a better job than a man. That is, over rough ground a horse's steps vary less in length than those of a man. He found also that hand-level surveying in the saddle has advantages over similar work on foot, provided a steady horse is procurable. All of the smaller hand instruments are readily transported in coat pockets and saddle-bags, bedding, tents and food in boats or on pack animals.

In steep mountainous terrain and in canyons where a horse is more often a hindrance than a help, reconnaissance is done on foot and beset with much physical exertion. In the absence of any trail it may require carrying packs and stopping to make camp when a promising site demands careful investigation. Since many river gorges and narrow valleys owe their origin to geological faults or crushing zones that were easily eroded by stream flow, search for evidences of such planes of weakness is of major importance in dam-site reconnaissance. However, not all gorges or canyons follow fault lines. The Grand Canyon of the Colorado River for many miles does not follow a single one of the many faults that intersect its high plateau region.

When a good site, or alternative sites, for a dam, have been found in a gorge or narrow valley, rough cross sections can be sketched in a notebook by determining elevations above river bed by hand-level or Paulin-type barometer, and by estimating distances across the river by rough paper triangulation, using the camera tripod head equipped for use as a miniature plane table. If aerial photographs happen to be available, distances may be scaled between identifiable points, but no great accuracy is thus afforded, since the scale of aerial photographic detail varies with relative height.

Individual photographs, overlapping on each other about 50% or more, are invaluable for viewing terrain that appears suitable for dams stereoscopically. On reconnaissance surveys the art of stereoscopic viewing with the naked eyes (thus dispensing with cumbersome stereoscopes) is worth cultivating. In fact, once the eyes have been trained to combine the overlapping

portions of two photographs, the stereoscopic view so obtained has the added benefit of undiminished clarity, whereas there always is a loss of light in a stereoscope. Eye strain, at first experienced, affects only the eye-ball muscles—not the optic nerves.

Whenever travel by water is feasible, a chartered boat has superior advantages over a regular passenger boat or towboat of a barge line, by permitting stops to be made to facilitate making observations. For trips of indeterminate length a steamboat is preferable to a motor boat as gasoline may not be procurable in the interior of the area to be explored. It is always possible to gather driftwood for firing a boiler, should the necessity arise. A stern-wheeler is safer for negotiating shallow water than a screw-propelled craft. On one reconnaissance for canalizing a 200-mile stretch of rock-bottomed river, the writer used a steamboat drawing only 23 inches. By keeping all fuel on a small barge, this draft was maintained uniform. It was thus possible to paint a scale of elevations above water level on the sides of the cabin and clear to the top of the pilot house for use in determining height of bank while traveling by sighting with a hand level. Approximate elevations up to about 30 ft above water level could so be estimated. All sites of merit were inspected in less than three days. The trip was expedited by having sleeping quarters and a small galley for cooking on board. Approximate river distances were scaled from aerial photographs.

Discharge Measurements

In the absence of a current meter, much can be accomplished towards determining the momentary discharge of a river, regardless of its size or stage, by timing floats or driftwood, preferably logs, in the swiftest part of the current. The relation between maximum central surface velocity and mean velocity in the entire cross section has become a serviceable tool for engineers, thanks to extended research by observers in several countries. In the case of small rivers subject to rapid changes in stage, especially when in flood, complete flood hydrographs of discharge are obtainable by this method by timing floats at, say, half-hourly intervals. The results so obtained have repeatedly been found superior to those of current-meter measurements. The V/V_{cs} method, as it is called, where V is the mean velocity in the entire cross section and V_{cs} is the maximum central surface velocity, is peculiarly suited to reconnaissance surveys, requiring only a stop watch and a tape. The difficult part of the job is the determination of the wetted cross-sectional area. Soundings are indispensable and horizontal distances may have to be estimated from aerial photographs, or by rough triangulation from a measured base. These difficulties are the same as in current-meter measurements made under the same circumstances. The V/V_{cs} method is applicable only to straight reaches between well-defined parallel banks, where all flow is confined to a single channel. The locus of swiftest flow may not always be exactly in the center of the channel, but in a straight stretch of river the axis of the current is usually found there. In doubtful cases it is advisable to time floats at several points. Since the thread of maximum velocity is not at the surface but about a foot below it, drifting logs that are well immersed and have no projecting limbs, are suitable for float observations. In no event should chips or surface trash be used for V_{cs} observations.

Table 1 presents a composite of V/V_{cs} ratios compiled from different sources. Where accuracy is desired the effect of Manning's n and length of hydraulic radius should be taken into account, but for quick estimates 0.8 is

an average value for smooth approximately rectangular cross sections. Ratios for trapezoidal cross sections run nearer 0.7. Triangular cross sections in bends should be avoided as their V/V_{cs} ratio is low and variable. For rough rock beds or weedy channels the ratio drops to 0.5 or 0.4. The V/V_{cs} ratio method has become increasingly popular in Europe and India for regular stream-gaging practice with either current meters or floats, notably for use on small streams whose flows vary half-hourly; also for very large rivers where any detailed procedure is not only time consuming, but involves the risk of losing current-meter equipment through entanglement with driftwood.

In the case of torrential type streams it becomes important to estimate the superelevation of the midstream water surface when computing the wetted cross-sectional area. It often amounts to several feet along the axis of swiftest flow, thus causing a marked increase in cross-sectional area. In large rivers this superelevation is negligible.

Table 1. Ratios of $V/V_{cs} = \dfrac{\text{Mean velocity in cross section}}{\text{Maximum central surface velocity}}$

Hydraulic Radius in feet	Values of Manning's n				
	n = .021	n = .024	n = .028	n = .037	n = .045
2	.75	.70	.66	.62	.53
3	.77	.72	.69	.64	.57
4	.78	74	.71	.66	.60
5	.79	.75	.72	.68	.62
6	.79	.76	.73	.69	.64
8	.80	.77	.74	.71	.66
10	.81	.78	.76	.72	.68
12	.81	.79	.76	.73	.69
15	.82	.79	.77	.74	.70
20	.82	.80	.78	.76	.72
30	.83	.81	.80	.78	.74
50	.84	.82	.81	.79	.77

Bank-Full Discharge Capacity

A formula devised by Gerald Lacey[2] gives a close approximation to bank-full discharge capacity in cubic feet per second of any river whose bed and banks are composed of erodible materials of the same kind as the river transports. The formula applies only to river channels with high well-defined banks, devoid of back channels, sloughs, and islands. The formula is written:

$$Q = \frac{b^2}{2.67} \tag{1}$$

where b is the width in feet between high banks and Q is in cubic feet per second. Since b is the only parameter that needs determination, and may have to be estimated from aerial photographs or by eye, it is advisable to take the mean of several estimates made at different crossings. The formula is empirical, having been derived from a large number of alluvial rivers in all parts of the world. Important to keep in mind is that b represents that width, which multiplied by the average bank-full depth, should give the area of the river's cross section for use in discharge computations. No limit is placed on the grain size of the alluvial bank materials, which may range from fine silt to coarse gravel. Example: a river 3600 ft wide in a straight reach where fairly steep parallel banks prevail for some distance on both sides, would have an approximate bank-full discharge capacity of 1,800,000 cu. ft per sec. The formula is not applicable to rivers flowing in rock beds or between erosion-resistant materials such as riprap or quay walls, nor does it apply to tidal estuaries.

River Gradients

When traveling by boat or launch, few things about a river are more difficult to estimate than its gradient. The following approximate method of estimating the slope of a river by reference to the coarsest particles in its bedload, yields answers closer than can be obtained from aneroid observations of altitude plus guessing at river lengths. Since a river profile does not plot as a straight line, observations should be made at frequent intervals. The slopes so obtained pertain to bank-full or flood flow only. The concept utilized is known as the stream's Competence for moving coarse rock debris. Competence, often stated as indicated by the largest gravel or boulder that a stream is capable of moving when in flood, is more accurately defined by the largest "rolling diameter" of such gravel or boulder. This amounts to viewing their rolling propensity as akin to that of a barrel. The length of a stone and its weight then become immaterial, since the pushing force of the flowing water is the same on each unit of length along its upstream face. The well-known DuBoys formula for tractive force: $T = wDS$ is used, which by transposition yields $S = \frac{T}{wD}$, where S is the water surface slope for bank-full or higher stage; T is the tractive force exerted at the bed, usually expressed in pounds per square foot or in kilograms per square meter; D is the depth at bank-full or higher stage at points where the largest stones come to rest; and w is the weight of a cubic foot of water plus its sediment content, taken

2. Stable channels in Alluvium, by Gerald Lacey, Min. of Proc. Inst. of Civil Engineers, London, Vol. 229, 1929-30, p. 270 and p. 274.

as 62.5 to 63.0 lbs. Fig. 1 was compiled by plotting the tractive force values that moved the largest stones that could be found in streams from all parts of the United States, against bank-full depth and slope. A few data were obtained also from rivers in other countries. The tractive force values were then converted into terms of "rolling diameter," taken as the thickest dimension of the stone. The consistency of the plotted values proved to be truly remarkable. On the other hand the plot revealed a wide difference in the tractive effort exerted by torrential flow in headwater streams, as compared with that exerted by tranquil flow in deep rivers. The reason is, steep headwater streams (omitting those of the cascading type) have extremely rough beds, develop a large amount of ineffective turbulence, and in addition entrain considerable free air which reduces the weight per cubic foot of water. The data so obtained showed consequently many inconsistencies, and were not used in the main diagram, which applies to tranquil-flow rivers having flood depths exceeding 10 ft. In the right hand lower corners are shown values applying to torrential headwater streams having flood depths of 10 ft and less. Slopes are shown as abscissas, in feet per mile at bottom, also in meters per kilometer at top of diagram. Slopes in terms of feet per foot, if desired for use in flow formulas, are conveniently obtained by adding three decimal ciphers to the meter-per-kilometer values. Rolling diameters, throughout, are expressed in inches. All slope values represent water surface slopes for ordinary and higher stages, but are not applicable to low-water stages because river profiles then consist of nearly level pools separated by riffles or crossing bars, and transport of coarse debris then ceases.

Loss of weight of stones by submergence in water, which is always allowed for in hydraulic laboratory studies of tractive force, is here eliminated by assuming a uniform specific gravity for all rock matter at around 2.6 to 2.8, which includes the majority of rock species found in streams, such as granite, gneiss, limestone, dolomite, quartzite, flint and the heavier sandstones. Not included are trap rock and basalt, specific gravity exceeding 3.0 nor the lightweight shales and shaly sandstones. Since the latter are ground up rapidly by streams, and the former are relatively scarce, it is believed that the diagram will prove useful in the majority of cases.

Field application of this method calls for accurate observations on gravel and boulder sizes. Any one not familiar with the path followed by coarse bedload travel in streams, which in general coincides with the path of strongest flood current, can glean much by talking with native river men, especially those operating launches. Since gravel and large stones are their bete noire, such men usually possess an intimate knowledge of the location of coarse debris, as at crossings and on islands. Many islands in midstream owe their origin to the deposition of gravel and coarser rock sizes, and whenever this is the case the largest fragments are usually to be found at the head of such islands. This greatly simplifies the securing of specimens. Another but more laborious method consists in scraping up bottom samples along the path of the heaviest bedload by dragging a 4-foot length of 4-inch steel pipe equipped with a flaring mouth and capped at its bottom end. This method necessarily is limited to small-sized stones, and presumes knowledge of the path of coarse bed-load debris. In no case should sand bars be sampled. Their constituents rarely contain any heavy bed-load material. Since tributaries, including the smaller, often are important sources of large rock debris, it pays to examine their mouths closely. If no alluvial fan or islands are seen at their mouths, this is evidence that the river's competence is equal to the task of rolling their largest sizes of debris. A quick visit often yields valuable information.

As regards the larger boulder sizes, it is of course necessary to ignore the "stationary" type, i.e., large blocks that have rolled down a mountain side and which the river cannot move. Such stationary boulders are readily recognized by their size and angularity. Fig. 1 includes boulder sizes up to rolling diameters of 4 ft and larger, which are not generally found in navigable rivers. From the writer's observations navigable rivers rarely transport stones having rolling diameters greater than 8 in., although the lengths of the stones may, of course, be somewhat greater. Examples of data used in compiling Fig. 1 are shown in the following table.

TRACTIVE FORCE DATA COLLECTED BY G. H. MATTHES

Examples Illustrating Method of Plotting

1) Sacramento River at Mi. 159 above Moulton Weir, rolls 3-1/2 inches to 4 inches gravel (Specimen 6 inches x 3-1/2 x 3 inches partly rounded weighed 3 lbs); slope 1.1 ft/mi. = 0.000,21; depth 28 ft. T = 0.37 lbs/sq. ft.

2) Sacramento River at Mi. 120 above Tisdale Weir rolls 2-1/2 inches to 3 inches dia. sub-angular gravel (one specimen weighed 1-1/4 lbs); slope 0.69 ft/mi = 0.000,14; depth 29 ft; T = 0.25 lbs/sq. ft.

3) Mississippi River above confluence with Ohio River rolls 3 inches dia. gravel; slope 0.55 to 0.60 ft/mi = 0.000,104 to 0.000,11; depth 34 ft; T = 0.19 to 0.24 lbs/sq. ft.

4) Missouri River below St. Charles, Mo. rolls 1-1/4 inches gravel; slope 0.71 ft/mi = 0.000,134; depth 12.9 ft; T = 0.108 lbs/sq. ft.

5) Kootenay River 20 mi. below Yarnell, Montana; rolls 13 to 15-inch boulders on slope 4-1/2 ft/mi = 0.000,85; depth 25 ft; T = 1.33 lbs/sq. ft.

6) Wenatchee River between Cashmere and Peshastin, Montana rolls 2-ft boulders, rounded; slope 30 ft/mi = 0.000,57; depth 6 ft; T = 2.15 lbs/sq. ft.

7) Bear River, Calif. mining debris 8 inches max. dia. moved on slope of 7 ft/mi = 0.001,325; depth 8 ft; T = 0.66 lbs/sq. ft.

8) Devil's River, Texas above gaging station, rolled a 9-ft boulder 4 ft. in dia. in depth of 40 ft on slope of 8.45 ft per mi. = 0.001,6; T = 4.05 lbs/sq. ft.

9) Rio Grande above El Paso, Texas (1932) rolled 1-1/4 inches and 1-1/2 inches dia. gravel on slope of 0.000,52, depth 5 to 6 ft (some of the specimens weighed 1/4 lb); was told coarser gravel had been found; T = 0.17 to 0.20.

Barometric Observations

Aneroid and Paulin type barometers are peculiarly suited for use in reconnaissance surveys where elevations do not require determination to the nearest foot. By correcting their readings for temperature changes of the air with the aid of the Smithsonian tables prepared for that purpose, errors can be reduced to within a few feet, provided the readings are taken in closed

circuits. Dependable results can be obtained only during steady weather conditions, and by closing circuits every two hours or more often. Since diurnal variation within such periods is almost wholly caused by changes in the temperature of the air, and but slightly by weather conditions, good working data are obtainable provided temperature readings are taken at frequent intervals. A blue sky with so-called "fair weather" clouds blown by strong winds is one of the worst conditions for barometric work. A completely overcast sky with gentle or no wind is best. On windy days, barometer readings taken on the lee side of a vehicle, building, ship's cabin or pilot house, invite serious errors, owing to unstable low-pressure areas at such points. Whenever practicable, a second instrument should be read at frequent intervals at a base station for the purpose of providing a correction curve. It will be readily seen that barometric observations are not satisfactory for reconnaissance work when travel is by boat on a river, because of the impracticability of making closed circuits or for providing for observations at a base station. In no case are barometric elevations of any value for determining river gradients.

Project Surveys

Surveys and stream-flow measurements needed in the design, construction and operation of river development projects in unmapped regions call for the same care and accuracy that are required for similar purposes in highly developed, well-mapped countries. This applies with equal force to projects contemplating water diversions for irrigation or for flood relief. Good topographic detail and an accurate net of level lines and transit traverses or triangulation control are of basic importance in all such cases. However, in the absence of sea-level elevations, an assumed datum for elevations is sufficient except in the case of harbor or navigable lower-river projects, where elevations above Mean Sea Level are of basic importance.

Accurate topographic and hydrographic survey operations in foreign lands are hampered by language differences, personnel problems, and by time lost in waiting for supplies or repair parts. Mechanical equipment of all kinds, from surveying instruments to motors, propellers and shafts for boats, needs many spares and replacement parts. Climatic conditions impose barriers to progress by limiting the time for field operations to specific times of the year. Monsoon rainfall during certain months, alternating with periods of extreme heat, call for planning survey operations with care. In some South American countries cutting down trees and clearing brush along river banks is prohibited except by special permit. In jungle areas clearing is costly and often a waste of time.

Floating equipment must be adapted to fit the job. Survey boats for field parties should be of the motorized shallow draft, scow-bow type, which permit of pushing barges and making landings anywhere; native craft, when motor driven, usually is adapted only for reconnaissance work, the transferring of survey men to points within the survey area, and for moving light supplies. Jungle and swamps bordering rivers, render transit traverse surveys impracticable. In such cases permanent triangulation stations must be established. Three-legged steel pipe markers are recommended for this purpose. For their erection, a work boat equipped with drop hammer and powered with a diesel engine is required. Quarter-boats are superior to camping in tents by providing better living conditions, better control of personnel, and by serving as bases of supply. During floods, when large areas

of valley lands are over-flowed, quarter-boats are invaluable. Important, in the matter of keeping native personnel contented, is the procurement of foodstuffs which they are accustomed to eating. On any job that is likely to take them long distances away from home, a thorough understanding with them must be had before hand. Good surveymen are sometimes found among foreigners, but they need careful screening; also they must be agreeable to working with American-made four-leveling-screw instruments which they regard as inferior for good results.

Instrumental Equipment

In tropical or desert regions where solar heat is intense, the metal parts of surveying instruments become too hot to handle with bare hands unless wound with muslin. Spirit levels need a lid-shaped cloth that permits of raising for noting the position of the bubble. This precaution if not taken causes the bubble to shrink to the size of a small pea, making it too sluggish for accuracy. Umbrellas are helpful to plane-table surveyors but not to transit or level men, who normally spend more time walking than standing at a station.

In planning the establishment of permanent gaging stations, it is advisable to pattern after the methods adopted by the federal engineers of the country visited, in order that velocity and discharge figures may be on a comparable basis. The reason is, that even with the best of instruments and care, measurements of discharge made with current meters are subject to systemic errors peculiar to the methods adopted for making the observations. These errors are in addition to the usual errors affecting stream gaging, which are of the order of 5% plus or minus from actual. A gaging station, once well established in connection with a project, is also likely to prove valuable as a permanent station for the local federal engineers. In such case, the record continued by them will possess consistency.

If a current meter in one's outfit is of the revolving-cup type, it is not good practice to try to check its rating by some improvised method. So long as the cups rotate freely when blown into, and the pivot point is in fair condition, it is best to use the instrument as is. A reasonable amount of wear does not, as a rule, affect the meter's performance in velocities of 1.0 ft per sec or greater. If a current meter needs overhauling or rerating it is best to complete such measurements with it as are of immediate importance before shipping it to the National Bureau of Standards, Washington, D.C., or to an Agricultural Experiment Station that has special facilities for meter rating. A request should accompany the meter, in such cases, to have it rated first in its existing condition, and again after overhauling. This enables corrections to be applied to the measurements last made with it.

Echo Soundings

The market now affords a choice of echo-sounding apparatus suited for use under a variety of conditions. The more sensitive electronic instruments record not only the depth of water, but in the case of harbors and estuaries the so-called interface layer of brackish water that separates fresh and salt waters, and also the top of flocculated clay deposits. Depth finders of this type are now available that record the depth to bedrock through sedimentary deposits overlying it, thus providing better information than is obtainable by making borings. This is of great assistance in planning seawalls and harbor

installations. As sound travels in water with velocities of 4,740 to 5,220 ft per sec., owing to differences in density due to temperature, salinity and suspended sediment concentrations, calibration of any electronic depth finder is required at intervals during each day's work. In water and in liquid mud calibration is quickly effected by lowering a flat piece of steel, usually a 4 or 5-ft length of T-bar or steel channel, suspended horizontally with flat side up successively at several known depths directly below the oscillator, thus checking the depths which it records. The rate of sound-travel through soil down to bedrock must be obtained from the instrument maker, or by trial at locations where depth of bedrock is definitely known. For use on river trips, small portable outfits are available, composed of an outboard oscillator that can be hung from the side of the vessel, a battery and graphical recorder, weighing in all some 200 lbs, and suitable for transporting in an automobile or truck. Since spare parts are difficult to obtain in foreign lands it is important to lay in a liberal supply at the outset together with necessary tools. On important dredging jobs it is advisable to have three sets, i.e., one in service, one in reserve, and one undergoing repair by the maker. Electronic instruments are delicate, hence require care in handling and in transportation. On the other hand, such instruments are capable of supplying a vast amount of information in a fraction of the time required for sounding with a lead line, thus soon repay their cost. Especial care must be exercised in suspending the oscillator alongside the boat to avoid its being in the path of air bubbles or foam from the bow. These interfere with sound transmission in water. To secure preliminary data, one engineer thoroughly familiar with the instrumental equipment can, with the aid of a launch runner and one deck-hand, obtain in one hour's time, enough data in a habor to keep a draftsman busy plotting soundings the rest of the day, assuming that sufficient shore markers or range lines have previously been provided. On long river stretches prominent features along the shores can be used as fixes. In some cases aerial photographs can be used to advantage for locating the approximate position of the boat, and for plotting the soundings. However, in accurate hydrographic surveys it is necessary to establish ground survey control lines with suitable markers and range lines. The position of the boat is then established by transit, or else by two surveyors on board armed with sextants reading angles on shore markers. By varying the rate of travel of the recording strip of paper, and also the speed of the boat, a wide choice of horizontal scales of the recorded soundings is obtainable. It is therefore desirable to select a make of depth finder that permits of changing the rate of travel of the recording paper strip. The vertical scale in most makes admits of no change. The accuracy of the recorded depths is usually of the order of half a foot, i.e., sufficient for most purposes.

Night Photography

In estuaries, as a rule, ebb and tide currents take different paths. Permanent records of their locations can sometimes be obtained by setting up a camera on a high point overlooking a sinuous stretch of river reputed to be troublesome for navigation, and exposing a photographic plate during a dark night on which illuminated floats register tracks. In the absence of any high ground from which to obtain suitable views it is necessary to erect temporary wooden towers. The method consists in making a first exposure in early evening while the light is still strong enough to produce a faint image of the shore lines. This accomplished, the shutter is closed and not opened again

until complete darkness prevails. It is then opened and left undisturbed throughout the period covered by the passage of the illuminated floats. Each float consists of a piece of lumber on which a small torch or an electric bulb, fed by dry battery, is mounted. Assuming that, initially, the ebb current has thus registered its track, the camera is left open and undisturbed until flood tide, when another series of illuminated floats are released. In this manner the positions of both currents are photographed on the same plate. This method can also be used for registering the main path of the entering salt-water wedge, the floats in such case being motivated by sub-surface vanes of the type used in tidewater hydrographic work. Night photography of the kind described originated in hydraulic laboratories, where the camera is suspended from a high support with optical axis vertical. The field method is necessarily confined to oblique exposures, but some excellent results have thus been obtained.

Aerial Photographic Maps

Aerial photography is a valuable aid in exploratory surveys as well as in the final planning of river projects. The methods employed for each of these purposes require separate consideration. For exploration and reconnaissance small-scale mosaics covering large areas are preferable because they provide good orientation for travel and also general information. Shoran, the radar method of triangulation control between ground points and aircraft, now provides a satisfactory control for small-scale mosaics up to 100 and 200 miles in length. A single flight made on a clear day at a scale of 1:50,000 will cover a strip about 7 to 8 miles in width, with one series of over-lapping photographs. These will generally cover the windings of the average river including the entire width of its valley. Enlarged to 1:10,000 scale, the prints permit of detailed study, and from them a map may be drawn by photogrammetry at a scale as large as 1:6,000 (1 inch equals 500 feet) with 25-foot contours in selected areas. A continuous mosaic map made up in the form of atlas sheets can be made on the original 1:50,000 scale, or if desired to 1:20,000 by enlargement. However, a mosaic on the larger scale would require good ground control in order to serve for planning of project structures.

A single flight, and the successive uses that can be made of the pictures, as here outlined, can be accomplished only by an aerial mapping concern having the latest photographic equipment and a specially built airplane, since the altitude called for is very high, i.e., in the neighborhood of 25,000 or more feet, depending upon the focal length of the camera. At lower altitudes more than one strip of exposures would be needed calling for additional flights, and the steps involving enlargement and mosaic building would correspondingly be more complex and costly.

In heavily timbered or jungle areas ground control often has to be limited to occasional astronomically determined points. In country of moderate relief this method yields fair results, but is less satisfactory in high mountainous areas owing to deflection of the plumb line. The results obtained with the conventional use of Shoran gives promise of superseding astronomic observations. This applies only to rivers whose water surface can be used as a reference plane for altitude and scale.

Photogrammetry has been used successfully for contouring proposed reservoir sites, thus permitting their approximate capacity to be estimated without ground survey. As an example, the capacity of a reservoir site on a river in Mexico, determined from an aerial photographic survey of a 60-mile

stretch of river flown without any ground control whatever, later was found by actual survey to be correct within 7%. Improvements in this art now render closer determinations of this kind practicable, except in cases where a proposed reservoir site is covered for the most part with a dense growth of jungle or timber that effectually conceals the ground surface. The method of drawing contour lines on the tops of the trees and correcting these later for average height of trees, is not recommended except when only a rough approximation is acceptable.

Aerial photographic maps for use in planning and for design purposes are best made to scales of 1:1,000 or 1:2,400 with 5 foot contours. If the photographs taken at the 1:50,000 scale are sharp, they may stand enlargement to as much as 1:10,000. But for the larger scales here mentioned, special flights will usually be required covering the specific areas selected for detailed study. If the vegetation is not dense, photogrammetry can provide contours at 5-foot intervals, but not in stretches where the terrain has very flat slopes. Only a plane table survey can supply contour lines in such places, and the interval may have to be as small as 2 feet. As previously stated, photogrammetric delineation of contours becomes impractical whenever the ground surface is obscured by dense vegetation. On the other hand, in steep mountainous terrain, photogrammetry is still preferable to plane-table surveying as regards time, cost and accuracy.

In deciding on a suitable horizontal scale for any map, two factors need consideration. If the scale chosen is to enable distances to be scaled accurately, the scale of the negatives must be commensurate with the final accuracy required. If, however, the scale is chosen to cover a wide expanse of working paper for overall project layouts, a lower order of accuracy is acceptable and the desired scale can be obtained by enlargement. This method, of course, enlarges the errors as well.

A single photograph, enlarged to 1:10,000 scale, would be large enough to serve as a plane-table sheet on which to plot accurate contour lines for project study. The topographer, in such event would have to determine the precise scale by reference to distances measured between objects readily identified on the ground. The use of aerial photographs on the plane table has many advantages over the orthodox way of making a map by starting with a sheet of paper with only the control points on it. It provides a higher degree of accuracy of detail and saves time. Furthermore, plane-table triangulation on aerial photographs is adapted for control for local surveys, as for barge terminals, small harbors and the location of soundings.

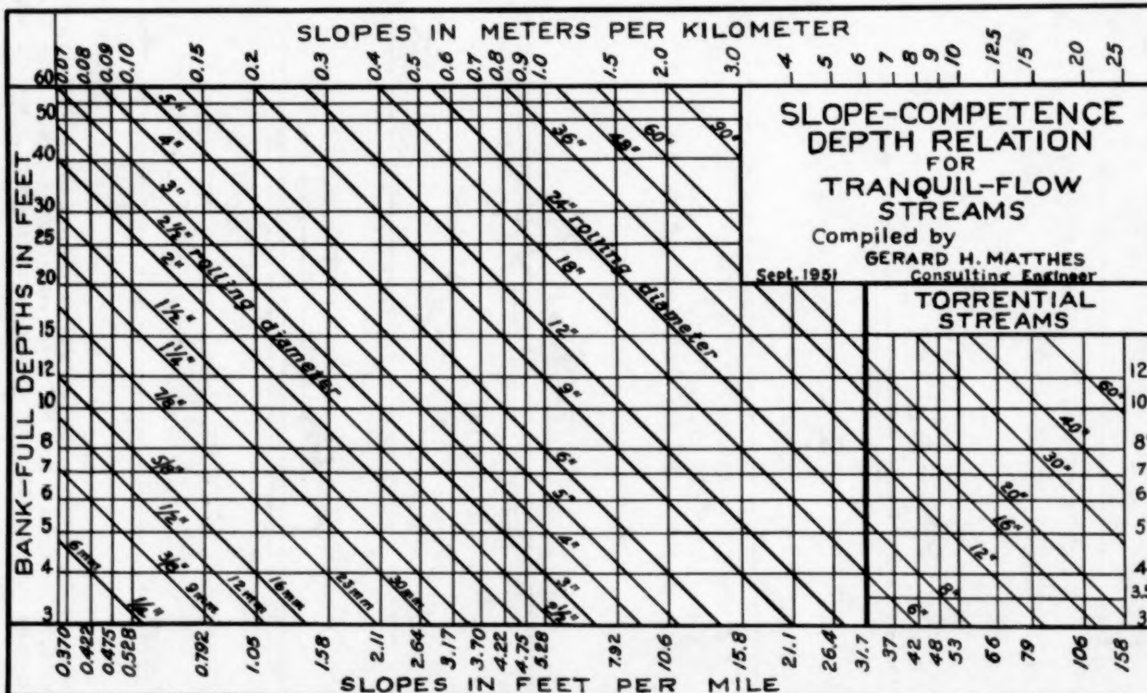
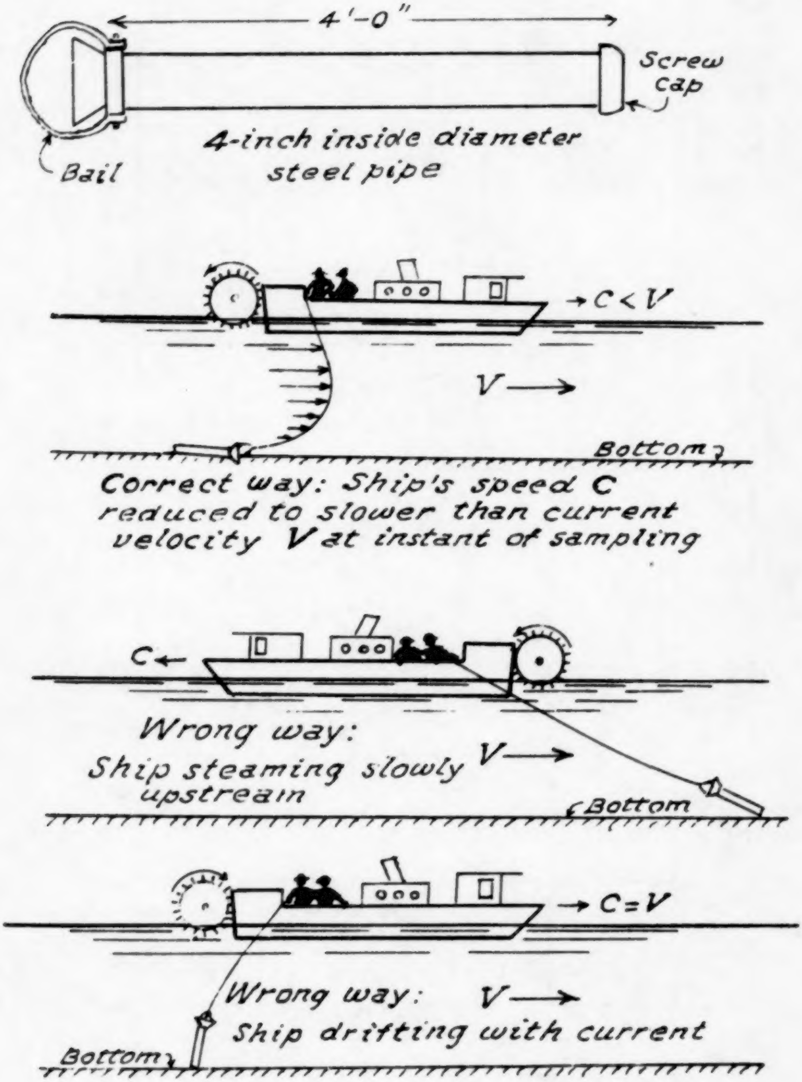


Fig.1-For estimating slope in terms of bank-full depth and rolling diameter in inches of <u>largest</u> stone.

RIVER BED SAMPLING



"Bed-load" sampling for securing the coarsest gravel and small boulders can be done only at river stages when sand no longer masks such material. The hand method has the advantage of "feeling" the action of the sampler when it bites into the bottom. Close communication between pilot and sampling crew is of paramount importance, as the boat's speed requires constant modification.

Fig. 2.